# FULL-SCALE STATIC LOAD TESTS OF DEEP SOIL MIXING PILES IN ALLUVIAL SILTY LOAMS OF ANDIJAN REGION

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***Abstract.*** *This article presents the results of three full-scale static compression load tests carried out on deep soil mixing piles installed in liquefiable alluvial silty loams of the Andijan region of Uzbekistan. The tests included piles of different length (7 m and 9 m) and mix grade (M40 and M60). Loading was applied in ten increments up to 240 kN with subsequent five-stage unloading. The measured peak settlements ranged from 8.19 to 13.04 mm, and residual settlements from 4.78 to 8.45 mm. A 49 % difference in peak settlement was observed between two piles of identical geometry and material, demonstrating significant within-site variability of deep soil mixing column quality. The findings emphasise the necessity of multiple control tests for site characterisation in seismic zones.*

***Keywords:*** *deep soil mixing, full-scale load test, settlement, alluvial soils, Andijan region, pile foundation, ground improvement.*

## Introduction

Deep soil mixing is one of the most widely used ground improvement technologies for foundations on weak, compressible, and liquefiable soils [1; 2]. The technology consists of in-situ mechanical blending of soil with cement or another binder to produce stabilised soil-cement columns of specified geometry and strength. In Uzbekistan, where significant areas of the Fergana Valley are underlain by liquefiable alluvial silty loams with seismic intensity reaching 8–9 points on the MSK-64 scale, the application of deep soil mixing for industrial and logistics facilities has expanded considerably during the last decade [3].

Despite this, the available local engineering practice rarely includes systematic full-scale load testing of deep soil mixing piles. Standard design relies on empirical formulas calibrated for bored concrete piles and does not account for the specific behaviour of soil-cement columns or the within-site variability of column strength, which can reach a coefficient of variation of 40 % [4; 5]. As a result, designers face uncertainty in predicting the actual load-settlement response and bearing capacity of installed piles.

The present study reports a programme of three full-scale static compression load tests performed on deep soil mixing piles installed for an agro-logistics facility in the Andijan region. The objective is to provide quantitative experimental data on the behaviour of such piles under serviceability load and to evaluate the variability of test outcomes for piles of nominally identical geometry and material.

## Methodology

The test site is located in the Andijan region, 8.4 km from the city of Andijan, on the second alluvial terrace of the Shakhrikhansay River. Geotechnical investigation included 161 boreholes drilled to 15 m depth with standard penetration testing in every borehole. The soil profile is composed of fill and silty loams in the upper 8.5 m, underlain by stiff loam, sandy loam, and

medium-dense sand. The seasonal groundwater table varies between 1.1 and 2.8 m below ground surface.

Three deep soil mixing piles were selected for the test programme. All piles had a diameter of 0.6 m. Pile No. 1 and pile No. 3 were 7 m long and produced from M40 grade soil-cement (mean unconfined compressive strength qu = 5.57 MPa). Pile No. 2 was 9 m long and produced from M60 grade (qu = 6.13 MPa). The piles were installed using the wet-mixing method with a single auger. Curing time before testing was 28 days for all piles.

The load tests were conducted in February–March 2026 in accordance with ASTM D1143 [6] and the requirements of GOST 5686-2020 for static compression testing of single piles. The reaction system used a 43-tonne hydraulic excavator providing dead load against a hydraulic jack. The loading programme consisted of ten equal increments of 24 kN, applied up to a maximum of 240 kN, with a 90 minute hold at each load level. Unloading was carried out in five increments of 48 kN with a 15 minute hold at each level. Settlement of the pile head was measured continuously by three dial gauges of 0.01 mm resolution mounted symmetrically at 120° around the pile axis. The bearing capacity Qult was determined using the Mazurkiewicz construction [7].

**Results**

The principal results of the three load tests are summarised in Table 1. The complete load-settlement curves, including loading and unloading branches, are shown in Figure 1.

***Table 1. Geometry, material, and observed response of the test piles***

| Pile | D, m | L, m | Grade | qu, MPa | Qmax, kN | Qult, kN | speak, mm | sres, mm |
|---|---|---|---|---|---|---|---|---|
| No. 1 | 0.6 | 7 | M40 | 5.57 | 240 | 248 | 12.20 | 8.45 |
| No. 2 | 0.6 | 9 | M60 | 6.13 | 240 | 245 | 13.04 | 8.31 |
| No. 3 | 0.6 | 7 | M40 | 5.57 | 240 | 249 | 8.19 | 4.78 |

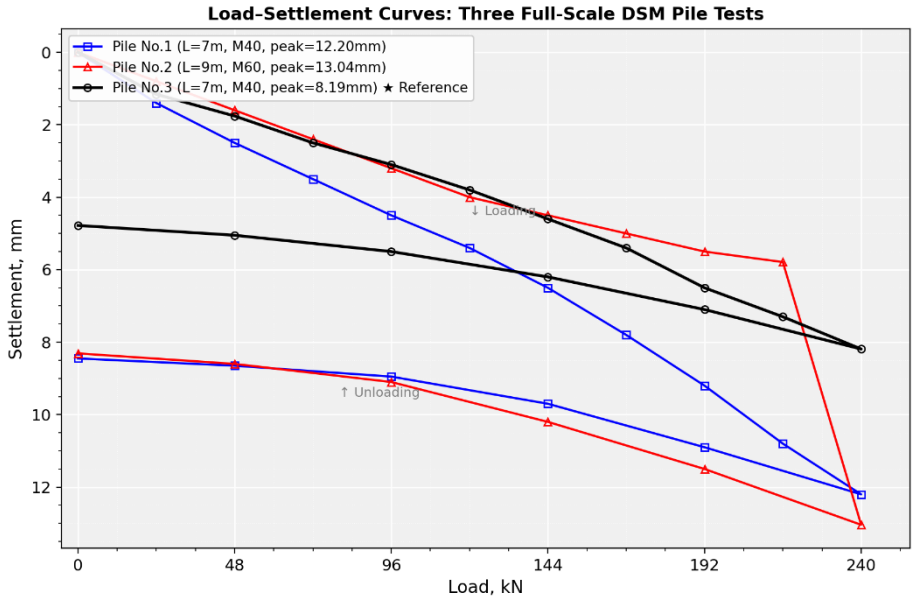



***Figure 1. Load-settlement curves of three DSM piles tested at the Andijan site***

The peak settlement at the maximum load of 240 kN ranged from 8.19 mm (pile No. 3) to 13.04 mm (pile No. 2), giving a relative spread of 59 %. The residual settlement after full unloading ranged from 4.78 mm to 8.45 mm, with a relative spread of 77 %. The Mazurkiewicz bearing

capacity values were similar for all three piles (245, 248, and 249 kN), but this similarity is misleading: at the same applied load, the settlement of pile No. 2 was 1.6 times larger than that of pile No. 3.

Three observations follow from the data. First, piles No. 1 and No. 3, although nominally identical in length (7 m) and grade (M40), differ in peak settlement by 49 % (12.20 versus 8.19 mm). Second, pile No. 2, which is longer (9 m) and made of a stronger mix (M60), shows the largest peak settlement of all three piles, indicating that nominal design parameters do not predict actual behaviour. Third, the residual settlements of piles No. 1 and No. 2 are remarkably close (8.45 and 8.31 mm), despite different lengths, which suggests a common irrecoverable deformation mechanism dominated by the pile-soil interface. Quantitative comparisons are summarised in Table 2.

***Table 2. Pairwise comparison of test results***

| **Comparison** | **Δ peak settlement** | **Δ residual settlement** | **Comment** |
|---|---|---|---|
| Pile No. 1 vs No. 3 (same length, same grade) | +49 % | +77 % | Spatial variability of execution quality |
| Pile No. 2 vs No. 3 (longer, higher grade) | +59 % | +74 % | Length and grade did not improve performance |
| Pile No. 1 vs No. 2 (different length) | +7 % | +2 % | Almost identical despite 2 m length difference |

The behaviour of pile No. 2 deserves separate comment. Up to a load of 216 kN, the load-settlement curve is approximately linear with a settlement of only 5.79 mm. At the next load increment of 240 kN, the settlement increases sharply to 13.04 mm. Such a response is characteristic of progressive failure rather than serviceability deformation. It is consistent with internal damage in the soil-cement column rather than with continuous shear mobilisation along the pile-soil interface.

**Discussion**

The wide variability of measured response between piles of identical nominal parameters is the principal practical finding of the test programme. The 49 % difference in peak settlement between pile No. 1 and pile No. 3 cannot be attributed to differences in geometry, mix grade, or testing procedure, all of which were identical for the two piles. The most likely cause is variability in the in-situ mixing process itself, including local variations in cement dosage, mixing energy, water content of the parent soil, and continuity of the soil-cement column [4; 5]. Within-site coefficients of variation of soil-cement column strength of up to 40 % have been reported in the international literature [4].

The paradoxical behaviour of pile No. 2 — longer and stronger but with the worst measured response — supports the view that the nominal design parameters of length and mix grade have less influence on actual settlement than the quality of column installation. This is consistent with observations in other studies of deep mixing technology [8; 9]. From the perspective of design practice, this means that bearing capacity values calculated from theoretical formulas using the nominal qu may overestimate the in-place response.

The close agreement between the residual settlements of piles No. 1 and No. 2 despite different geometries provides indirect evidence of the dominant role of the pile-soil interface in

irrecoverable deformation. If the response were governed primarily by elastic compression of the soil mass, the longer pile would be expected to produce a smaller residual settlement; the observed similarity points instead to a mechanism dominated by plastic slip along the column-soil contact.

**Conclusion**

Three full-scale static compression load tests of deep soil mixing piles were performed at an agro-logistics facility in the Andijan region of Uzbekistan. The measured peak settlements at 240 kN loading ranged from 8.19 to 13.04 mm, and the residual settlements from 4.78 to 8.45 mm. Two piles of identical nominal parameters showed a 49 % difference in peak settlement, demonstrating substantial within-site variability of deep soil mixing column quality. A longer pile of higher mix grade exhibited worse performance than shorter piles of lower grade, indicating that the quality of in-situ installation is the dominant factor controlling load-settlement behaviour. For practical design of deep soil mixing foundations in seismic zones of Central Asia, multiple full-scale control tests should be regarded as a mandatory part of the site investigation programme. A single test result cannot be considered representative of the entire foundation field.

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